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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CECOM-TR-94-9

Surface Ground Device

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John M. Tobias
CECOM Safety Office

June 1994

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13. ABSTRACT *(Maximum 200 words)*

This report details the concept, theory, prototype design and technical feasibility testing of the Surface Ground Device. The Surface Ground Device is a novel earth ground designed to provide a rapid means of electrically grounding mobile equipment. Basic grounding theory is discussed, with particular emphasis on the Surface Ground Device. In the report, resistance models are developed from basic electromagnetic theory for several grounding systems including the Surface Ground Device. Test results are compared to theoretical predictions and test results from other grounding systems. Preliminary results suggest that this device has promise as a suitable alternative for earth grounding mobile electrical equipment.

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1.0 Introduction

A novel method of electrically grounding mobile equipment, the Surface Grounding Device (SGD), is described in detail within this report. The SGD is a direct descendant of the Surface Wire Grounding System (SWGS), which demonstrated the feasibility of using the surface earth layer to effectively ground in realistic field environments.

1.1 The Need for Grounding

Equipment is grounded for several reasons. The overriding safety concern is for electrical fault protection. In our equipment, mobile systems are typically powered by external, high output mobile generators. If the equipment grounding conductor should become open, a fault within the equipment could possibly create a potential on the surface of the equipment. Personnel contacting the equipment may find that they complete a circuit to the source of the current, the generator, through the earth. This current through the body can be harmful or even lethal. By grounding the equipment, we attempt to equalize the potential between the possibly energized equipment surface and the earth. The lower the resistance to ground is, the better we can accomplish this. Because grounding systems, except in large fixed facilities, seldom achieve a very good ground, a current may still flow through a person who completes the circuit as described above. But the current, which is inversely proportional to resistance, is lower and may avert harm. The other two reasons for grounding are for lightning protection, and for noise control in signals. These reasons are ancillary to safety in our discussion, and, by achieving a good ground, we satisfy all three reasons. In our discussion, a "good ground" is one that achieves the minimal resistance to ground.

1.2 A Brief History of Grounding

The earliest cases of grounding were documented for lightning protection. A famous case (the earliest case I'm aware of) is mentioned by Golde in Venice where a tower over 100 meters high was wrecked by lightning nine times between the years 1388 and 1762. This destruction ceased after a lightning conductor was installed in 1766.[1] In its original form, the earth terminal was simply a rod driven into the ground, hence the familiar name "ground rod." Ground rods remained without variation until relatively recently. Beginning at the turn of the century, interest in grounding was renewed with the widespread advent of commercial electricity. This time, a major concern was the safe diversion of electrical fault currents. To prevent personnel injuries from electrical faults or lightning currents, it is desirable to create equipotential surfaces. As mentioned before, if an unfortunate person were to become part of a circuit by touching an energized surface, the results could be lethal. But if surfaces were bonded, e.g., electrically connected, each surface would be at the same potential. A person touching the electrically connected surfaces would not experience current flow across their body. What the ground rod (and the later grounding grid) does is to make

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[1] Golde, R.H., *Lightning Protection*, p.114, Chemical Publishing Co., New York, 1973.

the earth surrounding it an approximate equipotential surface. (We'll examine this in greater detail later.)

Most of the basic theoretical work in grounding theory was conducted between 1915 and the late 1930's, culminating in Dwight's relations for calculating resistances to ground in 1936.[2] These relations remain in standards published today. Major work in the calculation and design of grounding grids was performed early this century, and continues today for the power industry. Prediction of inhomogeneous soil effects on grounding systems has also been the subject of recent works, helped by the advent of computer numerical analysis methods.

The proliferation of military electronics has resulted in increased power requirements, resulting, in turn, in the increased need for field power generation. In tactical applications, the requirement to ground for personnel safety remains. The ground rod attempts to create an approximate equipotential surface near electrically powered equipments, and also serves the purpose of diverting lightning current away from sensitive equipment. A ground rod may be observed at any field site using electrical generators.

Yet the ground rod remains essentially unchanged from original designs over two hundred years old! In today's tactical environment, the potentially time-consuming task of ground rod installation is becoming a limiting factor in system deployment time requirements. Longer deployment times limit the equipment's mission, and affect survivability by allowing potential enemies more time to target the equipment.

An effort was begun in 1984 by the U.S. Army Human Engineering Laboratories (now the Human Engineering Directorate of the Army Research Laboratories, hereafter referred to as HRED) to construct devices for grounding that were easier, faster and technically equivalent to the old ground rod. Their reports, the Human Engineering Laboratories Grounding Analysis (HELGA) I[3] and II[4], detailed several candidate systems. Included were grounding mats, subsurface wire installation, and surface wire grounding. The culmination of this work was the recent successful fielding of the Surface Wire Grounding System, an item originally proposed by McJilton and Beek, later modified and tested by the U.S. Army Communications-Electronics Command's Research, Development and Engineering Center.

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[2] Dwight, H.B., *Calculation of Resistances to Ground*, Journal of the American Institute of Electrical Engineers, December 1936.

[3] Keiser, Bernhard, *Human Engineering Laboratory Analysis I, Technical Note 9-84*, U.S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, June 1984.

[4] McJilton, Walter N. and Beek, Charles R., *Human Engineering Laboratory Analysis II, Technical Note 4-87*, U.S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, July 1987.

The SWGS is illustrated in figure 1. It uses 15 small stakes and a long surface wire to achieve a suitable resistance to ground. This system, detailed in recent literature,[5] is proven by many test cases to equal or exceed ground rod performance, including ease of installation. It represents a logical extension of grounding technique to tactical applications, proving that nonconventional grounding systems are possible and practical.

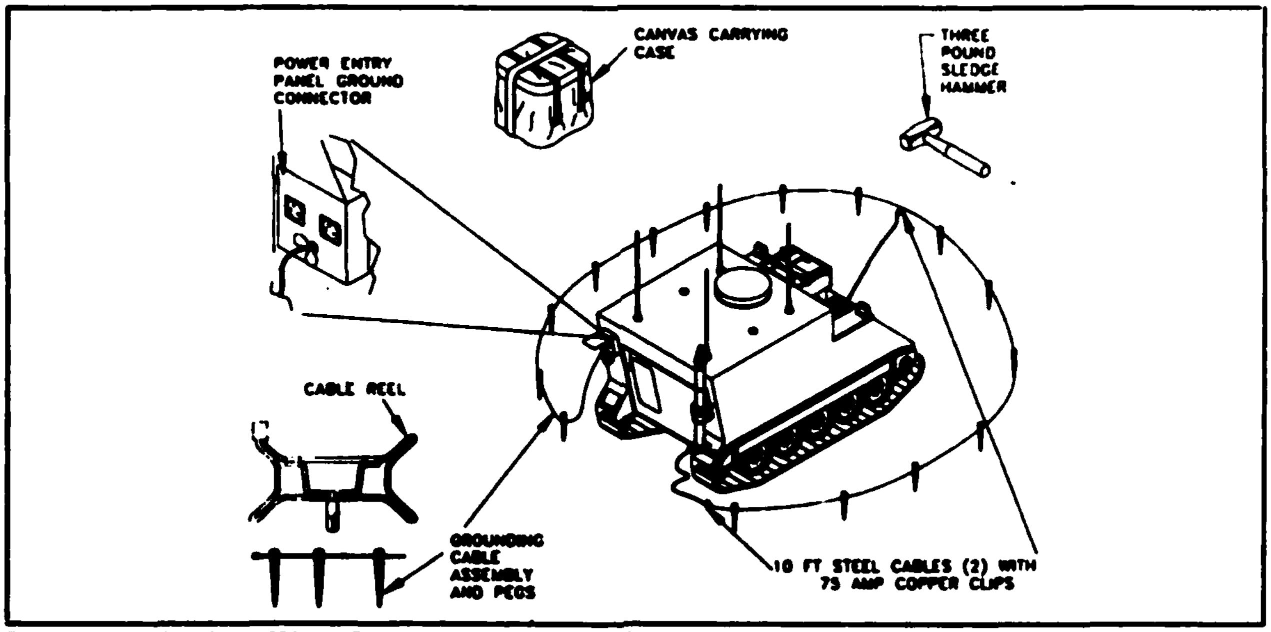

Figure 1. Surface Wire Grounding Kit (MK-2551).

In this report, we detail the theory, concept, and proof of principle of a new prototype grounding system, the Surface Ground Device. It was developed as another grounding alternative for tactical systems, where speed is paramount. We shall begin with basic grounding theory, develop the device concept using the theory, explain the prototype design, and present prototype test results.

[5] Tobias, John M., *Engineering Application Notes: Grounding Kit, MK-2551 A/U (Surface Wire Ground System)*, Research and Development Technical Report 94-8, U.S. Army Communications Electronics Command, Fort Monmouth, New Jersey, February 1994.

2.0 Basic Grounding Theory

Resistance to ground is based on the ability of the earth electrode to transfer the current to the bulk earth surrounding it. It does this, in the case of a ground rod, through a series of cylindrical shells, as illustrated in figure 2. The important electrical characteristic that all grounding equations are dependent on is the resistivity of the earth surrounding the electrode, designated here by the symbol ρ. As a simple example, we can derive an approximate expression for the resistance to ground of a simple ground rod.

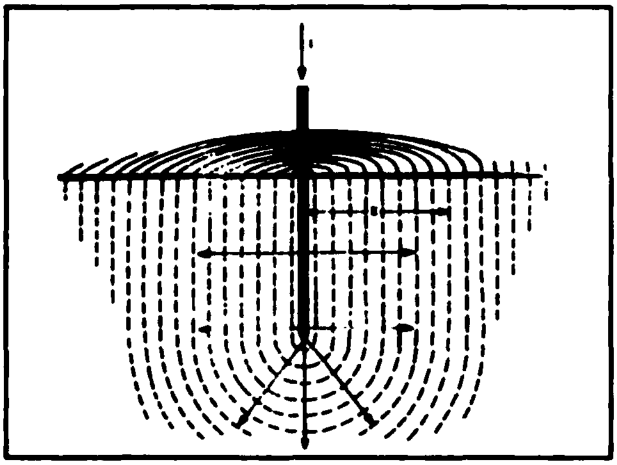

Figure 2. Grounding volume shells about the earth electrode.

Equation 1 yields the Current Density within earth as a function of x, the distance from the ground rod and l, the depth of the ground rod. Note that it is given by dividing the injection current by the surface area of the cylindrical shells about the earth electrode. It is in units of amperes per unit area, as the injection current is expressed here as I. The current could be up to 200,000 amperes in a maximal lightning event.

$$i_x = \frac{I}{2\pi x l} \qquad (1)$$

From Ohm's law, electric field strength E, in units of volts per unit length, may be found by multiplying the current density i by the soil resistivity, ρ.

$$E_x = \rho i_x = \frac{\rho I}{2\pi x l} \qquad (2)$$

Find the potential (voltage) as a function of x by integrating the field over x, the distance from the ground rod.

$$V_x = \int_r^x E_x \, dx \qquad (3)$$

We can substitute the electric field term E in equation 3, yielding equation 4, and integrate, which in turn yields equation 5, an approximate expression for the potential drop as a function of distance from the ground rod.

$$V_x = \frac{\rho I}{2\pi l}\int_r^x \frac{dx}{x} \quad (4)$$

$$V_x = \frac{\rho I}{2\pi l}\ln x - \ln r = \frac{\rho I}{2\pi l}\ln\frac{x}{r} \quad (5)$$

To find the resistance R, we apply Ohm's Law, dividing voltage by current, then substitute r=a (the radius of the cylindrical earth electrode) and x = 4l (a distance in which over 95% of the injection current is dissipated); this yields equation 6 which is approximately the accepted theoretical value for ground rod resistance, unadjusted for soil inhomogeneity or other conduction effects.

$$R = \frac{V}{I} \therefore R = \frac{\rho}{2\pi l}\ln\frac{4l}{a} \quad (6)$$

If we use the values for a standard 8-foot long, 3/4-inch diameter ground rod, we find that the resistance is approximately 0.005ρ.

It is interesting to note the dependence of these equations on the surface area that the earth electrode has in contact with the ground. A simple relationship could be established where the ground resistance is inversely proportional to surface area. This ceases to be true when mutual resistance and other effects are considered. As an approximation, if a greater contact area than that of the standard 6-foot ground rod can be achieved in some fashion, we predict a lower resistance to ground. The other consideration is that soil resistivity usually decreases with depth below the surface.

2.1 Step Potential

Equation 5 implies that a voltage gradient exists as a function of distance from the ground rod. The gradient is a function of the natural logarithm of the inverse distance from the rod.[6] If true, we can expect a voltage difference near an earth electrode undergoing current injection. This is known as the **step potential**, named after the potential drop across human feet in the space of a step. Step potential developed from lightning effects, or large fault currents, can be lethal. Figure 3 illustrates the hazards from step potential.

[6] Note that the limits of integration are transposed, as the point of observation is distance from the rod. This manifests itself as a logarithmic function of the reciprocal of x.

This effect can be a significant hazard in grounding systems. Our position is that any location out of doors, especially near grounding systems, is hazardous, and should be avoided during electrical storm conditions. The best possible course of action is to remain inside a grounded enclosure.

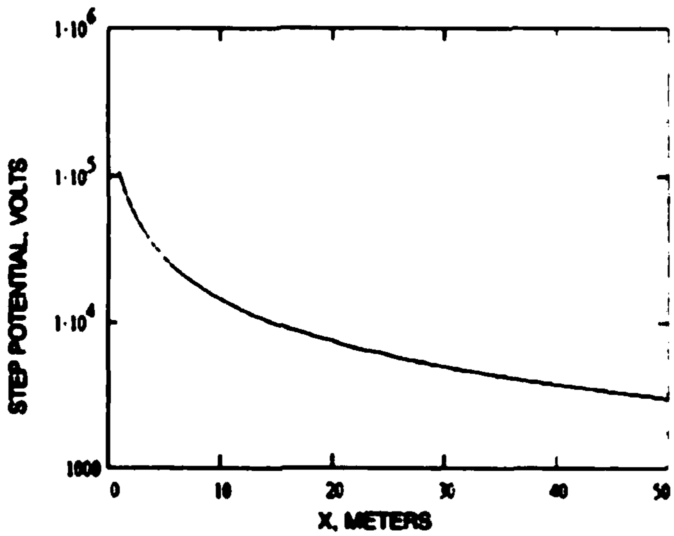

Figure 3. Approximate step potential profile as a function of distance from the ground rod.

2.2 Theoretical Evaluation of Surface Plate Grounding (SPG)

A theoretical model we may use is that for a smooth surface plate,[7] given by:

$$R=\frac{\rho}{\pi}\left[\frac{1}{a}\ln\left(\frac{a+\sqrt{a^2+b^2}}{b}\right)+\frac{1}{b}\ln\left(\frac{b+\sqrt{a^2+b^2}}{a}\right)+\frac{a}{3b^2}+\frac{b}{3a^2}-\frac{(a^2+b^2)\sqrt{a^2+b^2}}{3a^2b^2}\right] \tag{7}$$

Dwight's relations for ground resistance remain a standard method for ground resistance calculations. Using the plate dimensions a = plate width of approximately 30 cm and b = plate length of approximately 91 cm yields a value of $R=0.009\rho$. Using several plates of this size to ground will reduce the resistance further. If we separate the plates so that any mutual effects are minimized, we can approximate the resistance as a parallel connection; the final resistance to ground will be halved if two plates are used.

[7] Dwight, H.B., *Calculation of Resistances to Ground*. Journal of the American Institute of Electrical Engineers, December 1936.

2.3 Theoretical Evaluation of Surface Plate Grounding with Subsurface Connection Enhancement

A surface grounding plate, as modelled above, relies upon the ability of the surface plate to make a perfect connection to earth. In our model, we have not considered the effect of a surface layer of high resistivity such as snow or dry leaves, in calculation. We realize that the plate must be *under pressure* to approach "perfect" contact with the earth. Also, we wish to defeat the possibility of a highly resistive surface layer defeating the device properties. We then conjecture, borrowing from the SWGS concept, that a subsurface element will optimize this device. Let us picture the device as a plate with short embedded stakes that penetrate into the earth. This is expected to adequately defeat the possibility of a thin, highly resistive surface layer, and the enhanced surface area provided by the subsurface elements may also develop a lower resistance to earth. In modelling this device, we approximate it as a small grid, with the subsurface elements connected. In the model, we will approximate the plate as an open grid, since this is what is required for the validated model given in the reference.

First, from figures 2 and 3 within the reference, we determine the constants k_1, k_2 for the proposed (but arbitrary) plate dimensions w= 30 cm (approx. 1 foot) by l= 91 cm (approx. 3 feet).

$$k_1 = 1.27,\ k_2 = 6.00$$

Using the relations from the reference for each component:

$$R_{vanes} = \frac{\rho}{2\pi n L_1}[\ln(\frac{4L_1}{b}) - 1 + \frac{2k_1 L_1}{\sqrt{A}}(\sqrt{n}-1)^2] \tag{8}$$

where: (bracketed values are used in calculation)
ρ= soil resistivity, ohm-cm [normalized to 1 ohm-cm]
L_1= length of vane, cm [approx. 12 cm]
2b= equivalent diameter of each subsurface element, cm (assuming equivalent surface area if vane were cylindrical) [approx. 3 cm]
n= number of subsurface elements [n=14]
A= area of grid, e.g., plate area [A= 2730 cm^2]

Using these values yields approximately $R_{vanes} = 0.004\rho$.

Again using the relation in the reference:

$$R_{plate} = \frac{\rho}{\pi L}[\ln(2\frac{L}{\sqrt{2b}}) + k_1\frac{L}{\sqrt{A}} - k_2] \tag{9}$$

where all is defined as before, and:

L= total equivalent length of conductor in grounding grid, chosen as an approximation to be 10w (again, an arbitrary but conservative value, as we fully expect $L \gg 10w$ since it is a continuous plate).

Using these values in calculation yields $R_{plate}=0.008\rho$.

Now we calculate the mutual resistance given by the reference as:

$$Rsgd=\frac{R_{vanes}R_{plate}-R_{vp}{}^{2}}{R_{vanes}+R_{plate}-2R_{vp}} \tag{10}$$

where:

$$R_{vp}=\frac{\rho}{\pi L}[\ln(\frac{2L}{L_1})+k_1\frac{L}{\sqrt{A}}-k_2+1] \tag{11}$$

Calculation yields $R_{vp}= 0.007\rho$. Using this in the first relation, the final value for $R_{sgd}= 0.009\rho$. Again, use of several plates will lower the resistance further. Theoretical results, for the SPG and the SGD, found by two different methods validate each other. We expect that the result for the SGD presented here is conservative in that we expect a lower resistance than the result for the SPG. This is expected from the general theory of ground resistance, where earth contact surface area is inversely proportional to the final ground resistance.

3.0 Preliminary Results for Surface Plate Grounding

The grounding scheme evaluated first uses four pads of 1450 cm^2 each. These pads are integrally connected to each other and are separated by several feet. They are subject to a surface pressure of approximately $2X10^5$ Pascal. The results for the SPG, compared to a ground rod and MK-2551 Grounding Kit are in table 1.

Table 1. Comparative System Ground Resistances

System	Measured Resistance (ohms)	Theoretical Resistance expressed by resistivity.[a]	Measured Resistance expressed by resistivity.
Special (four pad)	201.0	0.006ρ	0.003ρ
Special (four pad with dry leaf surface)	1020.0	0.006ρ[b]	0.014ρ
Ground rod (8 foot depth)	148.0	0.005ρ	0.004ρ
MK-2551 Grounding Kit	104.9	0.001ρ	0.002ρ

Notes: (a) Dwight method, approximate single pad of 5800 cm^2 area.
(b) Dwight method, without consideration of high resistivity surface layer.

We can see that the actual measurements have lower resistance, and therefore perform better than predicted. The most significant result is that the surface plate system is competitive with a standard ground rod. It is also demonstrated that in the case of a highly resistive surface layer, performance is degraded by a factor of five. These results prompted the investigation of a surface grounding system with subsurface elements. We expect that the combination of surface plate and subsurface elements will appreciably lower the resistance.

4.0 Description of the Surface Ground Device

We constructed a prototype of a surface ground plate with subsurface element enhancement, which we have designated as the Surface Grounding Device (SGD), illustrated in figure 4.

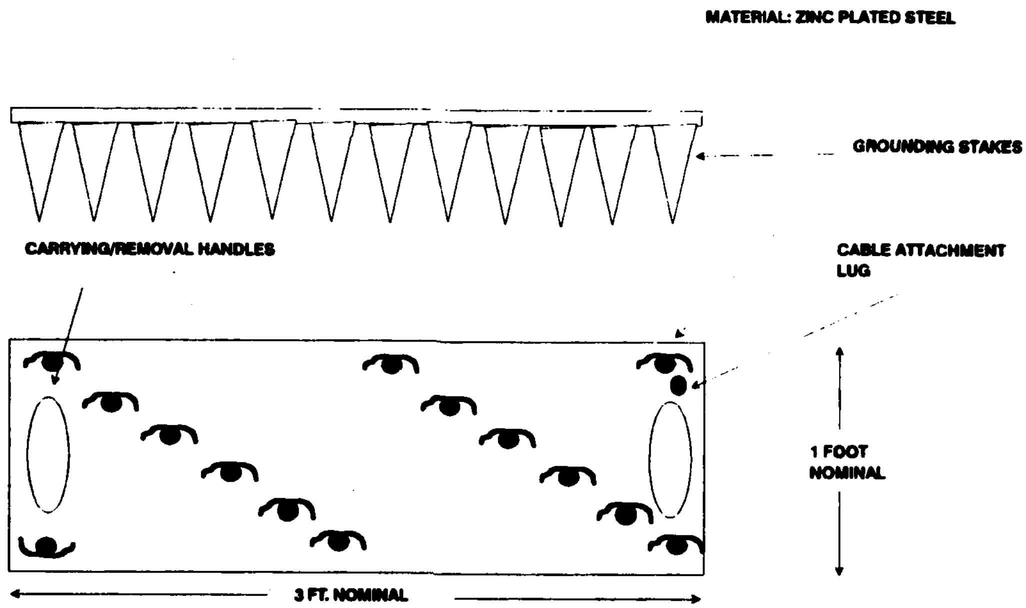

Figure 4. Side and bottom view of the SGD, approx. *1:6 scale.*

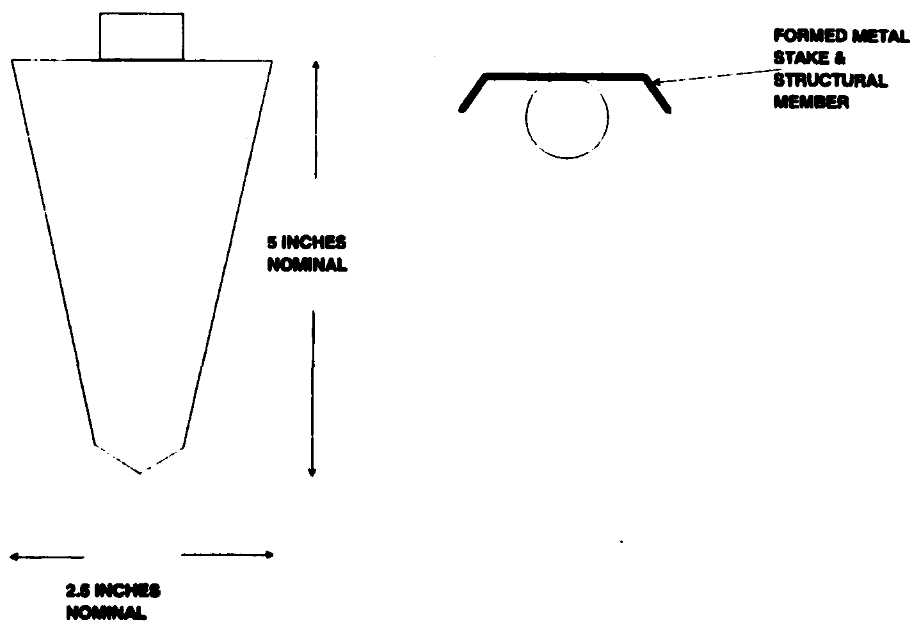

Figure 5. Subsurface vane detail.

It is constructed of high tensile strength steel, with 14 subsurface vanes. The vanes, detailed in figure 5, are arranged such that mutual effects are minimized. This is accomplished through having the maximum surface areas of each vane exposed to the surrounding earth in the staggered pattern. Recalling the basic grounding theory previously discussed, we remember that 95% of the current is dissipated within 4 times the length of the stake. In the staggered array, the maximum surface area of the vanes is not within this distance of each other. The intent of this arrangement is to improve overall performance. Our technique also lends some structural strength to the plate, as we intend for a vehicle to drive over the smooth side, to provide a high contact pressure for the surface plate. The vanes are similar to common stakes in that they are physically strong, yet lightweight. The third advantage of the subsurface element design is that it defeats the case of a highly resistive surface layer. Table 1 shows that a thin layer of very dry surface vegetation significantly changed the performance of the SPG. For easy system comparison, we have used the approximate device dimensions in our previous calculations.

4.1 Employment of the Surface Ground Device

In figure 6, we illustrate the intended application of the SGD. Two plates, as described in figure 4, are used here, with a HMMWV mounted system. If we consider this as a parallel connection to ground, realizing the plates are sufficiently separated to avoid significant mutual resistance effects, calculation yields a final resistance to ground of 0.004ρ-0.005ρ. In comparison to the results documented in table 1, the performance is again competitive with a standard ground rod. We surmise that the actual experimental values may be lower, possibly surpassing the performance of the standard ground rod.

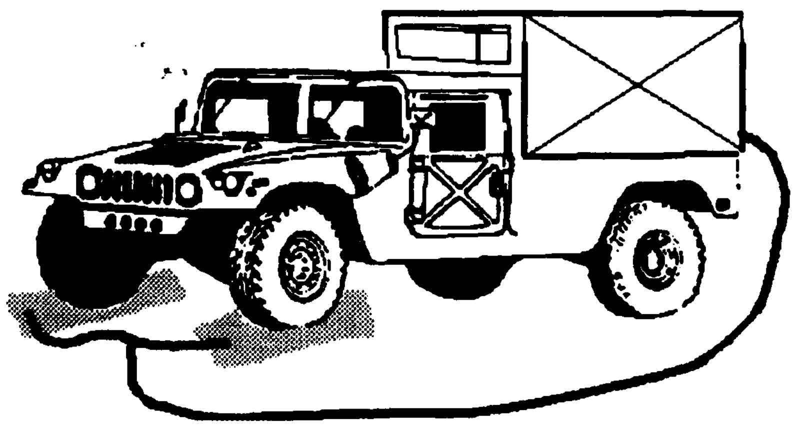

Figure 6. Intended application of the SGD.

5.0 Ground Measurements

To test the suitability of the SGD, we wish to determine the validity of our theoretical results and examine its performance compared to other grounding systems. We first determine the soil resistivity in the test location and then measure the earth resistance of each grounding system. In our test, resistance measurements were made using a Biddle model 250302 earth tester.

5.1 Soil Resistivity Measurement

The soil resistivity is measured by driving four electrodes into the ground in a straight line as in figure 7. Average resistivity for a particular depth can be found by modifying the distance between the stakes. In our test we want the resistivity of the soil at depths of 1.0 meter and 2.0 meters, to account for the depth of the candidate grounding systems. Probe depth should be 1/20th the separation distance. Each electrode is then connected to a separate (current and potential) terminal on the earth tester as in figure 7. Soil resistivity is calculated using the following formula.[8]

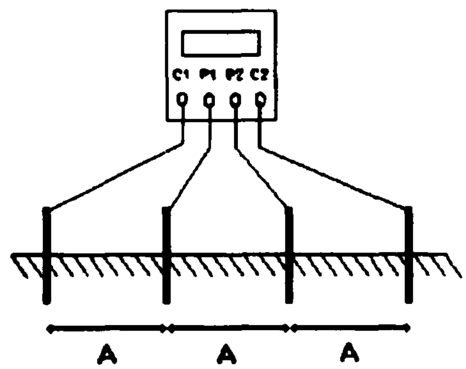

Figure 7. Soil Resistivity Measurement

$$\rho = 2\pi A R$$

This expression yields the average soil resistivity to depth A, in ohm-cm. A is the distance between each electrode and R is the earth tester reading in ohms.

5.2 Ground System Resistance

The earth resistance of the various ground systems is taken using the three electrode method, illustrated in figure 8. In this method, the ground rod is the reference point, a current electrode is placed a distance x from the ground rod, and the potential probe is placed at successive distances of 0.2x, 0.4x, 0.6x and 0.8x. The recommended distance to get a correct resistance measurement is 0.618x.[9] This distance will only provide an accurate measurement if the ground system and the current rod are sufficiently separated so that the

[8] Author Unlisted, *Getting Down To Earth*, Biddle Instruments, April 1981, pp. 29-30.

[9] *Instruction Manual, Digital Earth Testers DET 3/2 & DET 5/2*, Biddle Instruments, Blue Bell, PA.

cylindrical shells (mentioned in our primer on basic grounding theory) around each do not overlap. Consideration of mutual effects becomes important in grounding systems such as the SWGS, which covers a greater area on the ground. To verify the validity of a measurement, we plot the resistance profile versus the distance. The segment of the plot that is closest to zero slope (which should be approximately 0.618x) is the valid measurement. If the measurements on either side of the 0.618x distance show a steep slope, it can be assumed that the ground rod and the current electrode are interfering with one another and must be further separated. Note also that excessive separation will result in reading an incorrectly high resistance.

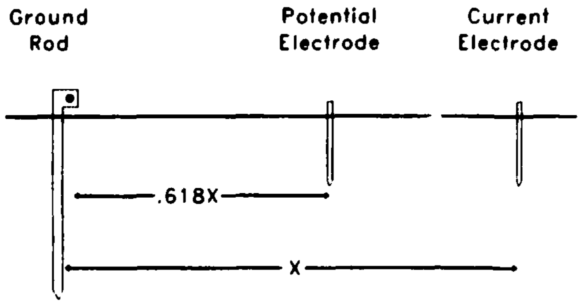

Figure 8. Test for grounding system resistance measurements.

This procedure is repeated for the SWGS, SPG, standard ground rod, and SGD.

6.0 Technical Feasibility Test

A Technical Feasibility Test was conducted May 17, 1994 at the Charles Wood Area of Fort Monmouth, New Jersey to determine the comparative effectiveness of the grounding systems considered so far, using the procedures listed in the previous section. Moderate precipitation was recorded for the past two evenings and the temperature was approximately 55 degrees Fahrenheit. The soil in this area is grass covered and has a sand/gravel consistency. Moisture was present in the surface vegetation from the previous evening's precipitation. This area has a high water table, estimated at approximately a four-foot depth, judging from the mud retained on an eight-foot ground rod after extraction. These conditions favor the ground rod, as it will penetrate the water table, resulting in low resistance to earth.

6.1 Ground Resistivity Measurement

ROD SPACING (CM)	RESISTANCE (OHMS)	RESISTIVITY (OHM-CM)
100	58.0	36442
200	23.8	29908

Remarks: The average resistivity is measured to a depth equivalent to the rod spacing. Despite recent precipitation, the average resistance decreases as a function of depth. These conditions favor the ground rod.

6.2 Standard Ground Rod (SGR) Resistance Measurement

Current Probe Separation, x = 1829 cm.

POTENTIAL PROBE DISTANCE		RESISTANCE (OHMS)	REMARKS
0.2X	366 cm	91.7	
0.4X	732 cm	95.0	
0.6X	1098 cm	96.0	Standard Measurement
0.8X	1464 cm	99.6	

Remarks: Very similar measurements over the length of the current probe distance indicate a valid resistance measurement at 0.6x.

6.3 Surface Wire Ground System (SWGS) Resistance Measurement

Probe Separation, x= 1829 cm, from leading edge of the SWGS.

POTENTIAL PROBE DISTANCE		RESISTANCE (OHMS)	REMARKS
0.2X	366 cm	76.3	
0.4X	732 cm	77.3	
0.6X	1098 cm	77.9	Standard Measurement
0.8X	1464 cm	80.7	

Remarks: Similar measurements over the range of x indicate a valid resistance measurement at 0.6x. The resistance is higher than normally expected from the SWGS compared to the ground rod, but we suspect it is due to the higher average resistivity closer to the surface.

6.4 Surface Plate Ground (SPG) Resistance Measurement

Current Probe Separation, x= 1829 cm. Both a one and two plate configuration were measured. Plate pressure is approximately 21800 Pascal, from weight of M-1037 HMMWV.

POTENTIAL PROBE DISTANCE		RESISTANCE (OHMS)		REMARKS
		1 plate	2 plate	
0.2X	366 cm	594	294	
0.4X	732 cm	595	296	
0.6X	1098 cm	594	295	Standard Measurement
0.8X	1464 cm	594	298	

Remarks: Very similar measurements over the length of the current probe distance indicate a valid resistance measurement at 0.6x. Previous tests have indicated that shorter distance measurements are valid for surface devices.

6.5 Surface Ground Device (SGD) Resistance Measurement

Current Probe Separation, x= 1829 cm. Note that both a one and two plate configuration was measured. Plate pressure is approximately 21800 Pascal, from weight of M-1037 HMMWV.

POTENTIAL PROBE DISTANCE		RESISTANCE (OHMS)		REMARKS
		1 plate	2 plate	
0.2X	366 cm	421	201	
0.4X	732 cm	424	204	
0.6X	1098 cm	426	205	Standard Measurement
0.8X	1464 cm	430	208	

Remarks: Very similar measurements over the length of the current probe distance indicate a valid resistance measurement at 0.6x. Previous tests have indicated that shorter distance measurements are valid for surface devices. Note that the one unit configuration has a 28% resistance improvement over the one plate SPG, and the two unit configuration has a 31% resistance improvement over the two plate SPG. We suspect this improvement would be much greater if the surface vegetation were dry.

6.6 Discussion of Test Results

In order to compare the test results, we must use the results in terms of the resistivity. These results are presented in table 2.

Table 2. Comparison of Tested Grounding Systems in Terms of Resistivity

System	Calculated Resistance	Actual Resistance
SGR	0.005ρ	0.003ρ
SWGS (MK-2551)	0.002ρ	0.002ρ
SPG (one plate)	0.009ρ	0.016ρ
SPG (two plate)	0.005ρ	0.008ρ
SGD (one plate)	0.009ρ	0.012ρ
SGD (two plate)	0.005ρ	0.006ρ

First, we note a discrepancy in the calculated versus actual SGR measurement believed to be from inhomogeneous soil, represented by the high water table present. Our theoretical model cannot account for inhomogeneous soil conditions.

The SWGS calculated and actual resistances compare nicely. Historically, the theoretical model we use yields a higher than actual resistance for this system.

We find the SPG calculated values lower than the actual, which is the reverse of what was expected. It is possible that slight bending observed when the M-1037 was parked on top of the plates resulted in suboptimal contact for portions of the plate. This would have the effect of significantly raising the resistance.

Values for the SGD compare more closely, although the theoretical values are again lower. It is possible that plate bending is mitigated by the subsurface vanes, resulting in improved contact. We also note that the SGD has approximately 16% more of total surface area in earth contact over the SPG, the improvement in resistance is approximately 30%. We also find that the actual two plate SGD resistance is comparable to the expected SGR resistance. It is possible that without inhomogeneous soil conditions, the SGD would be competitive with the SGR, as our original calculations indicate.

In terms of physical characteristics, the SGD was installed and removed easily, in a fraction of the time required for SGR installation/removal. Slight bending was noted when the M-1037 was parked on the SGD plates, but this was not permanent. Weight is a consideration as each SGD unit weighs approximately 35 pounds (16 kg).

Several design changes are considered for the next round of testing. Perforating the top plate of the SGD is a possibility, to reduce weight and provide for irrigation of the SGD. Also, welding the subsurface vanes instead of a knockout-pin construction may lower resistance. It was originally intended that the vanes be welded, but in the prototype the vanes are secured by pins, for easy replacement in case of damage.

7.0 Conclusion

From the results of testing we conclude that the SGD is feasible and most likely competitive with the ground rod under certain conditions. Under conditions where a rod could not be driven very deeply, or very dry conditions, the SGD would possibly outperform the ground rod. It has the potential to offer system designers a new alternative in tactical grounding. To develop the device into an item usable by the field, more testing is required. Testing should be performed under various soil conditions to determine under which conditions the SGD provides a better ground than the standard ground rod. Also required would be operational testing to determine durability and user friendliness. Advanced technical testing would be required to determine the system suitability under high current (lightning) conditions.

We plan to continue our experimentation with this and other alternative grounding devices, to provide more grounding options for mobile systems. The Surface Ground Device is a promising candidate system for further development, as demonstrated by these tests.

For further information on the Surface Ground Device, please contact the author at one of the following addresses:

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SUPPLEMENTARY

INFORMATION

DEPARTMENT OF THE ARMY
HEADQUARTERS, US ARMY COMMUNICATIONS-ELECTRONICS COMMAND
AND FORT MONMOUTH
FORT MONMOUTH, NEW JERSEY 07703-5000

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25 August 1995

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1. Reference telephone conversation with John O'Meara, Patent Attorney, USACECOM Legal Office, Patent Law Division, and John Tobias, CECOM Safety Office, 23 August 1995, SAB.

2. We request a distribution statement change of the subject report (AD# B186431) prepared by this activity. The original distribution restriction was enacted to prevent premature distribution of information with the potential for patentibility by the Government. This is no longer a concern as the patent application has been filed.

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\27 This report details the concept, theory, prototype design and technical feasibility testing of the Surface Ground Device. The Surface Ground Device is a novel earth ground designed to provide a rapid means of electrically grounding mobile equipment. Basic grounding theory is discussed, with particular emphasis on the Surface Ground Device In the report, resistance models are developed from basic electromagnetic theory for several grounding systems including the Surface Ground Device. Test results are compared to theoretical predictions and test results from other grounding systems. Preliminary results suggest that this device has promise as a suitable alternative for earth grounding mobile electrical equipment. Grounding, Electrical grounding, Surface ground device.
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